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Docket No.: 200313702-2 (1509-609)

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of
RUDIN, JOHN CHRISTOPHER *et al.*
U.S. Patent Application No. 10/587,200
Filed: January 16, 2007
For: APPLYING COLOUR ELEMENTS AND BUSBARS TO A DISPLAY
SUBSTRATE

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: Group Art Unit: 2871
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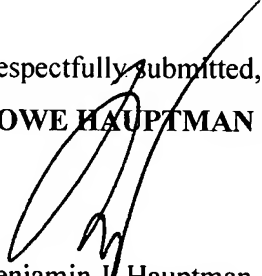
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Respectfully submitted,
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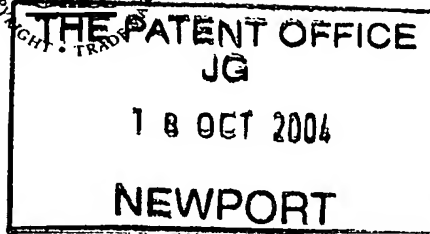
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200404910-1 GB

2. Patent application number

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0423134.6

3. Full name, address and postcode of the or of each applicant (underline all surnames)

Hewlett-Packard Development Company, L.P.
20555 S.H. 249
Houston, TX 77070
USA

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

8557 886001

4. Title of the invention

Display Device With Greyscale Capability

5. Name of your agent (if you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

David J. Marsh
Hewlett-Packard Ltd, IP Section
Filton Road, Stoke Gifford
Bristol BS34 8QZ

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8

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DUPLICATE

DISPLAY DEVICE WITH GREYSCALE CAPABILITY

FIELD OF THE INVENTION

5 The present invention relates to display devices which have greyscale capability, and to methods and components for manufacturing the devices.

BACKGROUND TO THE INVENTION

10

Many display devices use a layer of electro-optic material which changes at least one optical property when a suitable electric field is applied across it. Examples of electro-optic materials include nematic or smectic liquid
15 crystals and electrophoretic materials. Liquid crystal displays (LCDs) typically comprise opposed planar cell walls with electrodes on the inner surface of each wall. The cell walls are spaced apart and enclose a layer of a liquid crystal (LC) material. An alignment layer or
20 structure may be provided on the inner surface of each cell wall, over the electrodes, to induce a desired uniform alignment of molecules of the LC material. Typically, electrodes on one surface may comprise rows of parallel conductive strips and electrodes on the other
25 surface may comprise columns of parallel conductive strips at right angles to the rows. Picture elements (pixels) are defined by the overlap of row and column electrodes. When sufficient voltage is applied at a pixel, the LC material in the pixel is switched from its surface-aligned
30 state to a different alignment state. The display includes means for distinguishing between the different states, for example one or more polarisers. In conventional nematic LCDs, the LC material reverts to the

surface-aligned state when the electric field is removed from a pixel. Row and column electrodes are easy to manufacture, but conventional nematic liquid crystal displays require quite complex matrix addressing
5 (multiplexing), and the number of pixels that can be addressed is limited.

An alternative to this passive matrix addressing is active matrix addressing, wherein each pixel is activated by a
10 thin film transistor (TFT) which is part of an array. The transistor maintains the pixel in the required state until the display is next refreshed. A problem with active matrix displays is that large area TFT arrays are difficult to manufacture, particularly on polymer
15 substrates.

Bistable displays offer a route towards high-complexity, high-quality, low-cost electronic displays. Each pixel can be switched either dark or light and will remain
20 switched even after the applied voltage is removed. Complex displays with good contrast and viewing angle can be constructed without active matrix addressing. Known bistable displays use ferroelectric smectic LC materials. More recently, bistable displays have been developed which
25 use nematic LC materials and microstructures to support two different LC alignments, for example as disclosed in EP 1 139 151 and EP 1 271 226. However, in order to be able to show full colour it is desirable that an LCD can display shades of grey.

30

It has been proposed in US 4,712,877 to provide a ferroelectric LCD with greyscale by providing an insulating film on an inner surface of one cell wall, with

ITO (indium-tin oxide) transparent electrodes on top of the film. The thickness of the film varies within a pixel so that the distance of the electrode on the film from a conventional planar electrode on the other cell wall varies. The ferroelectric LC has a threshold electric field above which switching occurs, but below which switching does not occur. The electric field strength experienced by the ferroelectric LC material for a given electrode voltage differs within the pixel so that at a lower applied voltage some areas of a pixel will experience an electric field above the threshold and be in an 'on' state and some areas will experience an electric field below the threshold and be in an 'off' state. At a higher applied voltage more or all of the pixel will be switched to the 'on' state. A problem with this approach is that the thickness of the LC layer varies, which compromises the optical performance of the display and ultimately limits the number of accessible grey levels. Another problem lies with the difficulty of forming ITO electrode structures on a film of varying thickness on a cell wall. Further problems are inherent in the use of ferroelectric materials, relating to the difficulty of obtaining uniform alignment in a robust display, and of obtaining a ferroelectric LC material with a sufficiently wide operating temperature range.

US 5,257,122 describes an alternative ferroelectric LCD with greyscale capability. In this device, one of the cell walls is not uniformly planar and parallel with the other. One cell wall either has steps or a slope on which are formed electrode structures, while the other cell wall is planar and has planar electrodes. An alignment (orientation) layer is provided on the stepped or sloping

electrode structures, in such amounts as to fill in the steps or gradient so as to present a substantially planar alignment surface to the layer of ferroelectric LC material, the alignment surface being parallel with the
5 other cell wall. This device has a uniformly thick layer of LC material but suffers from the same problems inherent with all ferroelectric devices, and with the difficulty of manufacturing stepped glass and infilling with an alignment layer to provide a sufficiently smooth surface.
10 The demonstration cell described in US 5,257,122 is not a guide to practical device fabrication.

SUMMARY OF THE INVENTION

According to an aspect of the present invention there is provided a display device with greyscale capability,

5 comprising:

a first cell wall of a glass or plastics material having a substantially planar inner surface spaced apart from and opposed to a second cell wall having a substantially planar inner surface,

10 said substantially planar inner surfaces being substantially parallel to each other;

a layer of an electro-optic material between the cell walls;

a plurality of first electrode structures provided on
15 the first cell wall and at least one second electrode structure provided on the second cell wall, overlapping regions of first and second electrode structures defining pixels;

the electro-optic material being switchable from a
20 first optical state to a second optical state when subjected to a suitable waveform of applied electric field;

wherein the shortest distance between the electro-optic material and at least one of the electrode
25 structures varies substantially within the area of a pixel whereby electro-optic material in a first region of a pixel will be subjected to a higher electric field strength than electro-optic material in a second region of that pixel when a voltage is applied via a first and
30 second electrode across the pixel so that electro-optic material in said first part of said pixel will switch at a lower applied voltage than electro-optic material in said second part, thereby providing greyscale capability.

By substantially varying the shortest distance between the electro-optic material and one of the electrodes within the area of a pixel, the electric field strength exerted on the material varies. Thus, for a display with a threshold voltage, at a lower applied voltage only some of the pixel will switch, while at higher applied voltages, more or all of the pixel will switch. Thus, each pixel has greyscale capability. The greyscale capability is achieved by subpixel halftoning rather than by having more than two stable states or by any temporal dithering. The terms 'threshold voltage' and 'threshold electric field' refer respectively to the minimum voltage applied to the electrodes and the minimum electric field applied across the electro-optic medium to achieve switching. For a bistable display the threshold electric field is that needed to switch the electro-optic material from a first stable state to a second stable state. After removal of the electric field the material will remain in the second state until driven back to the first state by a suitable different electric field. For a monostable display with a threshold, the term 'threshold electric field' or 'switching threshold' refers to the minimum electric field needed to switch the electro-optic material from one optical state to another, for example changing a helical nematic LC to a substantially homeotropic alignment. After the electric field is removed, the electro-optic material reverts to its original optical state.

A display without a threshold is capable of continuous inherent grey levels but it is not possible to passively matrix. The effect of the variation in field strength across the pixel in this case leads to a modification and

quantisation of the overall electro-optic response.

In one embodiment, the shortest distance between the electro-optic material and a first electrode structure varies substantially continuously, for example by having the electrode structures slope at a nonzero angle in relation to a substantially flat surface of the electro-optic material. In another embodiment, the shortest distance varies in a series of discrete steps, either by forming the first electrode structures with discrete steps or by forming a series of dielectric steps on top of planar first electrode structures. The steps do not need to be linearly spaced in plan or in vertical height.

The term 'electro-optic material' is used herein to denote a material which changes at least one optical property when a suitable electric field is applied across it. The optical property may be visible to the naked eye, for example in an electrophoretic display in which coloured or opaque charged particles migrate to a cell wall under an applied electric field of appropriate sign. Suitable electrophoretic materials are well known to those skilled in the art of electro-optic display device manufacture. The electro-optic material may comprise a nematic or smectic liquid crystal. For a liquid crystal material the change in optical property may be visible to the eye (for example a change from a clear to a scattering texture) or the different optical states may be distinguished by means such as a dissolved pleochroic dye and/or one or more polarisers in ways well known in the art of LCD manufacture per se. For convenience the invention will be described herein with reference to liquid crystal display devices, but it will be understood that the invention is

not limited to LCDs.

In a preferred embodiment the display is bistable, for example a post-aligned bistable nematic or a hole-aligned
5 bistable nematic display as described, respectively, in EP 1 139 151 and EP 1 271 226 the contents of which are incorporated herein by reference. In another embodiment the display may be an electrophoretically-controlled bistable nematic device, for example as described in
10 GB 2 394 781, the contents of which are incorporated herein by reference.

In order to switch the LC between stable states the electric field applied across the LC has to exceed the
15 threshold. By putting the dielectric step between the electrode and the LC the electric field experienced by the LC will be reduced. Thus the applied voltage needed to switch the LC can be controlled by varying the thickness of the steps. Increasing the amplitude of a switching
20 pulse will cause more of the steps to switch and hence increase the proportion of the device that switches into one of the two states, ultimately reaching a fully-switched state. The eye averages the areas of the pixel that are in each state to give a perceived grey level.

25

In an alternative embodiment the display may be an active matrix display in which pixels are defined by overlap of rectangular electrodes driven by transistors in a TFT array on one cell wall with a continuous electrode on the
30 other cell wall.

As alternatives to bistable display modes, the display may operate in various LCD modes, for example twisted nematic

(TN), supertwisted nematic (STN) or hybrid aligned nematic (HAN). The LC material may optionally be chirally doped for device applications that require the LC to adopt a twisted structure, or to produce tilted smectic
5 ferroelectric materials. For displays in which the LC has an electro-optic threshold, for example TN or STN, some parts of a pixel may be substantially completely switched (where the electric field experienced by the LC exceeds the threshold) while other parts (where the electric field
10 experienced by the LC is below the threshold) are substantially unswitched. Greyscale is obtained by subpixel halftoning. In display modes without a sharp threshold voltage, such as HAN, the LC will switch more with increasing electric field up to a maximum field
15 strength at which the pixel is fully switched. Thus, grey levels within a pixel may vary continuously where the minimum distance between the LC and an electrode varies continuously across the pixel, or the grey levels may be quantised as a series of steps, where the minimum distance
20 varies discontinuously as series of steps.

The variable spacing may be provided by means of one or more dielectric coatings or layers provided over planar first electrode structures. This arrangement has the
25 benefit that it can be manufactured from conventional cell walls with planar row and column electrodes. However, it is preferred that the layer of LC material has substantially constant thickness to reduce unwanted optical effects. Accordingly, in a preferred embodiment,
30 an inner surface of each first electrode structure is spaced apart from the planar inner surface of the first cell wall by a distance that varies within the area of a pixel, and a dielectric covering material overlies at

least a part of the first electrode structures so as to present a substantially planar surface to the layer of liquid crystal material, substantially parallel to the inner surface of the second cell wall. The inner surfaces
5 of the first electrode structures may be spaced from the first cell wall by one or more dielectric materials or by one or more conductors applied to the first cell wall. Preferably, the spacing material is a dielectric material which may conveniently be an adhesive material that
10 adheres to the cell wall itself or to a polariser or other optical film affixed to the cell wall. An inner surface of a cell wall in contact with the layer of LC material is provided with a suitable alignment layer to enable the LC to be switchable between either of two stable states (eg
15 in PABN mode). This device provides a bistable nematic LCD which has planar cell walls and a constant LC layer thickness.

The amount by which a dielectric step reduces the electric
20 field experienced by the LC layer for a given voltage applied between the first and second electrodes will depend on the dielectric constant of the material of the step. For a typical dielectric such as SU-8 10
(Microchem) and a particular device - in this case a PABN
25 display - we have found that each 100 nm step increases the switching threshold (ie, the external potential difference that needs to be applied between the first and second electrodes to achieve switching) by about 1 V. The values may be different for different display modes.
30 Preferably the shortest distance between the first or second electrode and the LC varies by at least 100 nm within the area of a pixel. In a preferred embodiment, a surface alignment is provided on the first electrode

structures, inducing a single substantially uniform alignment to adjacent molecules of the liquid crystal material. For a PABN cell, the surface alignment preferably induces local homeotropic alignment, an inner
5 surface of the second cell wall being textured with posts to provide bistability. However, each surface alignment could also be provided on the other cell wall.

The electrode structures may be spaced from the LC
10 material by a wedge of a dielectric material, to provide a continuously varying minimum distance between an electrode and the LC material, or by a series of dielectric steps provided on the electrodes. A preferred minimum dimension for each step, in plan view through a cell wall, is 10 μm .
15 A particularly preferred minimum dimension is in the range 20 - 100 μm . Typically, the maximum dimension in plan view will be the length of the cell wall.

There may optionally be provided on top of each grey-level
20 dielectric step, alignment features such as a grating structure, or posts or holes such as in a PABN or HABN cell. If alignment features are provided, several of these will be provided on top of each dielectric step.

25 The cell wall assembly which comprises the first cell wall, first electrode structures and dielectric covering material may be manufactured and sold as a separate item suitable for use in manufacturing a display device. Accordingly, another aspect of the invention provides a
30 cell wall assembly comprising:

- a first cell wall of a glass or plastics material having a substantially planar surface;
- a plurality of first electrode structures provided on

a substantially planar surface of said first cell wall, each of which is spaced from the surface of the first cell wall by a spacing material; and

5 a dielectric covering material which overlies at least a part of the first electrode structures so as to provide a substantially planar surface;

wherein the distance of a surface of each first electrode structure from the planar surface of the first cell wall varies substantially within a specified area.

10

Typically, the electrode structures will have a length which is much greater than their width and the distance of a surface of each first electrode structure from the planar surface of the first cell wall varies substantially within the width of the electrode structure. Overlap of the first electrode structure with a second electrode structure in a display device will produce a display in which the distance from the LC layer varies substantially within the area of each pixel.

20

The cell wall assembly may optionally be provided with an alignment layer or structure for inducing one or more desired alignments in adjacent molecules of LC material when incorporated into a display, in a manner known per se.

25

According to a further aspect of the present invention there is provided a method of manufacturing a cell wall assembly for a display device with greyscale capability, the method comprising:

30

forming on a surface of a transfer carrier, a dielectric structure which extends in a direction perpendicular to said surface by a distance which varies

within a specified area;

forming on said dielectric structure a plurality of electrode structures;

adhering said electrode structures to a major surface
5 of a cell wall of glass or a plastics material; and
removing the transfer carrier.

The surface of the transfer carrier is preferably substantially planar, and this planarity defines the final
10 surface quality of the cell wall assembly. It is also preferred that the major surface of the cell wall is substantially planar. An advantage of using a carrier with a planar surface is that the surface quality of the substrate does not have to be very good.

15

In a preferred embodiment the thickness of the adhesive layer is varied such that the two sides of the cell wall assembly are substantially parallel.

20 To facilitate energising of the electrode structures the method may further comprise forming at least one busbar in the dielectric structure and forming at least one of the electrode structures in contact with the busbar.

Preferably, a plurality of busbars is formed in the
25 dielectric structure and each electrode structure is in contact with a busbar. The busbars will typically be linear structures that will extend along the length of the cell wall. Any desired spacing may be used, for example they may be 50 to 200 μm apart, notably about 100 μm
30 apart, and they may be many metres in length. It will be understood that the term 'cell wall' is used herein, where the context permits, to refer to a display substrate which may be used as manufactured or which may be formed into a

plurality of separate pieces, each of which may be used to construct a display.

Other display components, such as colour filters, UV-
5 filters, and polarisers or other optical films may optionally be formed on the transfer carrier and transferred to the cell wall with the electrode structures and dielectric structure. The term "optical film" is used herein to denote a film which modifies at least one
10 property of light incident thereon. If a polariser is laminated on the inner surface of the cell wall then birefringence of the cell wall becomes unimportant and a cell wall with uncontrolled birefringence can be used.

15 The dielectric structures may be formed on the carrier by any suitable means, for example embossing, micromoulding, laser ablation or photolithography. In a preferred embodiment the dielectric material is optically transparent and is formed by UV micromoulding, as taught
20 in WO 96/34971, the content of which is incorporated herein by reference.

Once the dielectric structures and busbars have been formed a transparent conducting material (eg, PEDOT:PSS
25 [HC Starck Baytron P] or ITO) is applied and, if required, patterned, for example using a serial (eg, laser ablation) aligned technique. PEDOT may be applied by any suitable coating techniques, notably by inkjet printing.

30 The busbars and electrode structures are transferred by adhesive onto the cell wall. The alignment of the busbars and electrode structures relative to each other on the transfer carrier is preserved on the cell wall

According to a further aspect of the invention there is provided a method of applying to a display substrate transparent electrode structures and addressing busbars in
5 a defined alignment relative to each other, the method comprising the steps of:

(a) forming on a substantially planar surface of a transfer carrier, a series of dielectric structures each of which has a length and a width and which extends in a
10 direction perpendicular to said surface by a distance which varies substantially within said width, each dielectric structure comprising electrode-receiving surface regions separated by a levee, adjacent dielectric structures being spaced apart to define a trench
15 therebetween;

(b) forming said busbars by at least partially filling each of said trenches with an electrically-conductive material;

(c) depositing a layer of a translucent conductor
20 material on said electrode-receiving surface regions and in contact with said busbars to form a series of electrode structures defined by said levees;

(d) affixing said electrode structures and levees to a display substrate by means of a dielectric adhesive
25 material; and

(e) removing said transfer carrier.

Other aspects and benefits of the invention will appear in the following specification, drawings and claims.

30

The invention will now be further described, by way of example only, with reference to the following drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Figures 1 and 2 illustrate stages in the manufacture
of a cell wall assembly having busbars and electrode
structures in a predetermined alignment, in
accordance with an embodiment of the present
invention;

10 Figure 3 illustrates stages in the manufacture of a
cell wall assembly in accordance with an alternative
embodiment of the invention;

15 Figure 4 illustrates a stage in the manufacture of a
cell wall assembly in accordance with another
alternative embodiment;

20 Figure 5 is a schematic sectional view through part
of a liquid crystal display device in accordance with
another aspect of the invention;

25 Figure 6 is a schematic sectional view similar to
that of Figure 5, through part of a device in
accordance with a further alternative embodiment;

30 Figure 7 is a similar view to Figure 5, of another
embodiment of a liquid crystal display device in
accordance with an aspect of the invention;

 Figure 8 is a schematic sectional view through part
of a different embodiment of a liquid crystal display
device in accordance with a further aspect of the
invention;

Figure 9 is a micrograph of part of the display of Figure 8; and

Figure 10 shows optical microscope pictures of switching of the device of Figure 8.

DETAILED DESCRIPTION

In the drawings, different parts have been enlarged or reduced to aid illustration of the invention. The drawings, except for Figure 9, are therefore not to scale.

A transfer carrier 1 is shown in Figure 1a. The carrier 1 comprises a base film 2 on which is coated a planar conductive layer 3. The carrier 1 may be rigid or flexible. In this example, the base film 2 comprises 150 μm thick PET and the conductive layer 3 is copper metal of about 1 μm thickness. In this example, the copper layer 3 is optically flat and has been passivated by immersion in 0.1 N potassium dichromate solution for 5 minutes, rinsed with deionised water and air-dried. Alternatively, the base film may itself be a conductor.

A multiple-level pattern of dielectric steps 4 is formed on the surface of the conductive layer 3 of the carrier 1 by embossing a polymer structure. The dielectric material is optically transparent and could be formed by alternative techniques, for example by micromoulding as taught in WO 96/35971. A trench 6 is formed in the dielectric structure 4. If necessary, the trench 6 is plasma-etched to remove polymer from the bottom of the trench 6. Metal, in this example nickel, is then electroplated into the trench 6 to form a busbar 8 (Figure

1b). It is preferred that the conductor 3 forms the cathode of an electrolytic cell with a nickel anode and standard nickel sulphamate-based electrolyte. Plating may be carried out with DC, with pulsed or biased AC current used to fill in the trenches 6 completely. Other known electroplating or electroless plating techniques may be employed. Suitable metals include nickel, copper and gold. The busbars 8 are linear structures which will run across the length or width of the display substrate (cell wall) to which they are transferred. They are typically about 100 μm apart and up to many metres in length. The busbars 8 are about 5 x 5 μm is cross-section and have a low resistance that in use will apply an applied voltage evenly across the device. The metal of the busbar 8 is opaque but it is small enough not to reduce the aperture too much.

To form electrode structures, a transparent conductor 10 is deposited onto the dielectric structure 4 and busbars 8, as illustrated in Figure 1c. The conductor 10 may comprise indium oxide, tin oxide, indium tin oxide (ITO) or the like, but is preferably an organic conductor such as PEDOT:PSS (HC Starck Baytron P), which may be applied by a printing technique such as inkjet printing. The transparent conductor is then selectively etched or bleached to provide transparent electrodes 10. Standard photolithographic techniques can be used to prevent the conductor contacting more than one busbar 8. In the preferred embodiment, PEDOT:PSS is selectively bleached by UV light to form the electrode structures. Alternatively, standard photoresists and etching or chemical deactivation may be employed.

It will be understood that, for simplicity, only a single dielectric structure 4, busbar 8 and electrode track 10 are shown. A plurality of similar dielectric structures, busbars and electrode structures will be formed, each
5 electrode structure 10 typically comprising one of a series of parallel row or column electrodes.

After forming the electrode structures 10, the resulting structure is treated with a transparent transfer adhesive
10 14 and the final display substrate 12 is laminated and the adhesive 14 is cured (Figure 2a). In a preferred embodiment the transfer adhesive 14 is a UV-curable material such as NOA81 (Norland Optical Products) but may be thermal- or moisture-cured. The display substrate 12
15 is preferably a plastics material, for example PEN (DuPont Teijin Teonex Q65), PES (Sumitomo Bakelite) or polyArylate (Ferrania SpA - Arylite), but could comprise glass, preferably a UV-translucent glass.

20 The adhesions in the assembly shown in Figure 2a are tuned such that when the transfer carrier 1 is peeled off, the adhesion breaks at the surface of the conducting carrier substrate 3. The whole of the rest of the structure remains adhered to the display substrate 12, as
25 illustrated in the cell wall assembly 5 of Figure 2b. This surface is flat so that the resulting LC layer will be a constant thickness. The electrode structures 10, however, are embedded at different distances from the cell wall 12. The distances are set by the initial embossing
30 of the dielectric structures 4 (now a dielectric covering layer for the electrode structures 10).

In this embodiment, one of the dielectric steps 4 is the

full thickness of the busbar 8. It may be desirable to make the steps less than the full thickness of the busbar 8 to avoid increasing the switching threshold too much. The width of the step could be kept small to minimise the non-switching region. Alternatively, the initial trench 6 may be made somewhat shallower and the metal may be overplated to form a busbar 8 that extends beyond the dielectric structures 4 as illustrated in Figure 4.

Turning now to Figure 3, an alternative process for providing an electrode-patterned substrate is illustrated. The transfer carrier 1 of Figure 3a is similar to that of Figure 1a except that the embossing 4 includes additional raised lines or walls 101 (levees) which are significantly taller than the surrounding features and define the boundaries of the pixel or electrode line. Typically the levees 101 are from 4 - 10 μm tall and 3 - 7 μm wide. Preferably they have a smooth surface to reduce the wetting of the subsequent coatings. In Figure 3b the busbar 8 is formed in the trench 6 in a similar manner to that of Figure 1b. A liquid solvent-based transparent conductor 103 (eg a dispersion of PEDOT:PSS [HC Starck Baytron P]) is coated into the areas (channels or pixels) defined by the levees 101. The coating process may be any known deposition technique, preferably gravure or flexo-gravure coating, or inkjet deposition. The dispersion 103, in this example PEDOT:PSS dries and forms a substantially uniform layer 10 to form the transparent conductor. The surface properties of the embossing resin 4 are such that the film formation provides a uniform coating while preventing any coating over the levees 101. The layer 10 makes ohmic contact with the busbar 8. As illustrated in Figure 3e, the bottom corners of the levees

101 may include an internal radius 104 feature matched to minimise the meniscus effect forming an undesirable thicker conductive region closer to the levee.

5 Turning now to Figure 5, a display device with greyscale capability 22 comprises the cell wall assembly 5 of Figure 2b, including a first cell wall 12a and first electrode structures 10a, formed as previously described and in ohmic contact with the busbar 8. The device 22 in this
10 example is a liquid crystal display device and has a layer of electro-optic material 20 which comprises a nematic LC. A first surface alignment 18a is provided on the innermost surface of the cell wall assembly 5. The surface alignment 18a in this example comprises a PABN surface
15 textured with posts to provide bistable alignment to adjacent molecules of the nematic LC material 20. Other bistable alignments could be used, or conventional alignment materials such as rubbed polyimide if the display is monostable, for example a supertwist or HAN
20 cell.

A second cell wall 12b is of conventional construction, being formed from a flat glass or plastics material and having second electrode structures 10b formed thereon by a
25 conventional etch technique using ITO. A second surface alignment 18b is provided on the second electrode structures 10b, in this example inducing homeotropic alignment in adjacent LC molecules. Means for distinguishing between different optical states are
30 provided, in this example polarisers 16 which are adhered to the outer surfaces of the cell walls 12. It will be understood that surface alignments 18 could be transposed; ie the PABN surface alignment could be provided on the

innermost surface of the second cell wall and the homeotropic surface alignment could be provided on the first cell wall assembly 5. The second cell wall 12b may be spaced apart from the first cell wall assembly 5 by
5 conventional spacing means (not shown) for example microbeads or pieces of glass fibre or polymer fibre. Suitable spacing means are well known to those skilled in the art of LCD manufacture.

10 The inner surfaces of both cell walls 12 are substantially planar and parallel to each other, and the layer of nematic LC material 20 is of substantially constant thickness. The shortest distance between the LC material 20 and one of the first electrode structures 10a varies
15 within the area of the pixel illustrated in Figure 5. Above a maximum threshold voltage all of the visible pixel area is in an 'on' state. For a bistable display, when the voltage is reduced or removed the pixel remains in the 'on' state. To switch the pixel to an 'off' state, a
20 suitable pulse is applied.

The LCD of Figure 6 is similar to that of Figure 5 except that the second cell wall assembly 5b is constructed similarly to that of the first cell wall assembly 5a.
25 Dielectric steps 4b separate the second electrode structures 10b from the LC 20. The second cell wall assembly 5b may be constructed by a similar transfer method to that used to make the first cell wall assembly 5a. The transparent adhesive 14b of the second cell wall
30 assembly 5b may be formed of the same adhesive material as the transparent adhesive 14a of the first cell wall assembly. In this arrangement, the shortest distance between the LC material 20 and one of the first electrode

structures 10a varies within the area of the pixel, as does the shortest distance between the LC material 20 and one of the second electrode structures 4b. In this arrangement the cell may be symmetrical in a plane through the LC layer 20 parallel to the cell walls 12 and may be more easily constructed because the electrode variation may be shared between the two cell wall assemblies.

Figure 7 illustrates an alternative embodiment of a bistable LCD in which the polariser 16 on the upper cell wall 12a is provided on an inner surface, in this example between the first cell wall 12a and the adhesive 14, so that birefringence of the first cell wall 12a does not affect the display appearance. The switching voltage differs according to the shortest distance of the electrode structure 10a and the LC molecules 20. Each dielectric step 4 increases the switching threshold voltage. In order to switch the LC between stable states the electric field applied across the LC has to exceed a threshold. By putting the dielectric step between the electrode and the LC the electric field experienced by the LC will be reduced. Thus the applied voltage needed to switch the LC can be controlled by varying the thickness of the steps. In the illustration in Figure 7, sufficient voltage has been applied via electrode structures 10a and 10b to align LC molecules 20a, in the outer regions, in the 'on' state. The applied voltage was insufficient to switch LC molecules 20b, in inner regions, from the 'off' state. Increasing the amplitude of a switching pulse will cause more of the steps to switch and hence increase the proportion of the device that switches into one of the two states, ultimately reaching a fully-switched state as illustrated in Figure 5. The eye averages the areas of

the pixel that are in each state to give a perceived grey level. LC molecules under the busbar 8 in Figure 7 are switched, but are not visible under the opaque busbar. The busbar is narrow (about 5 μm) so is not readily
5 visible.

Turning now to Figure 8, an alternative embodiment of the invention is illustrated. Dielectric stripes 4 coat the first cell wall 12a. Typically these are made from a
10 polymeric material and can be made by using a microreplication technique. The dielectric stripes increase the distance between the LC molecules 20 and the electrode 10a which increases the voltage that has to be applied before the electric field experienced by the LC
15 exceeds the switching threshold.

An experimental display cell was manufactured as follows. A 76 mm diameter glass substrate 12a carries an ITO electrode structure 10a, formed in a manner well known per
20 se. The electrode surface is initially subjected to a plasma ash treatment for 5 minutes to aid adhesion of resist. That surface is then coated with SU-8 10 UV-curable epoxy resin from MicroChem by spin-coating 0.5 ml of 25% v/v SU-8 10 (in gamma-butyrolactone) at 4000 rpm
25 for 40 seconds. The intermediate coated product is baked at 110°C for 10 minutes and then exposed using hard contact lithography. A chrome-on-glass mask with 25 μm wide lines and spaces was used. After further baking at 110°C for 10 minutes, the intermediate coated product is
30 developed using Microposit EC solvent to give thin parallel stripes.

The resulting intermediate coated product is now coated

with thicker stripes by spin coating 0.5 ml of 40% v/v
SU-8 10 at 4000 rpm for 40 seconds, followed by the
baking, lithography, baking and developing steps as
described above, with one difference. In the lithography
5 step the mask is at right angles to the first exposure and
the exposure time is increased because of the thicker
resist.

This gives four steps of different heights, as shown in
10 the SEM image of Figure 9. The approximate thicknesses
are: thin stripe (4a) 170 nm; thick stripe (4b) 360 nm;
crossing points (4c) 440 nm. The resulting substrate is
then ready for use in a glass device. The substrate may
be manufactured in any desired area, with the ITO 12a
15 etched to form suitable electrode structures, for example
parallel conductive strips, and then cut to the
appropriate size for the device.

To make a PABN device, a homeotropic alignment treatment,
20 for example a chrome complex, is put on top of the steps.
A pattern of posts is formed on the other substrate 12b
using hard contact lithography in a suitable resist, for
example Shipley s1813. A chrome-on-glass mask with 0.6 μm
wide lines and spaces is used for two exposures at right
25 angles to each other. For each exposure the illumination
is tilted by a few degrees. Upon developing this gives
the posts that are tilted by a few degrees along one of
their body centred diagonals. Before use in a device the
resist needs to be hard baked. The other substrate may be
30 formed with dielectric stripes in a manner similar to the
first substrate or it may have a conventional
construction. In a preferred embodiment the second
substrate has similar dielectric stripes to the first.

Beads, in this example about 3 μm diameter in glue are used to set the cell gap. Any other known means for setting the cell gap may be used, including forming spacers from the resist during the SU-8 patterning step.

5 The cell is then capillary-filled with a negative dielectric nematic LC material, eg ZLI-4788-000 from Merck. The LC may optionally be doped with a surfactant to improve switching, for example trimethylpropane tris(3-mercaptopropionate). Typically about 1% w/w of the
10 additive is used.

The results shown in Figure 10 were acquired on a device made using the above method. From left to right, the switching in each 300 μm pixel is as follows:

15 Fig. 10a: all regions 'on';
Fig. 10b: all on except for crossover regions (4c);
Fig. 10c: all on except for crossover regions (4c) and thick stripe regions (4b);
Fig. 10d: only non-stripped regions (4d) on;
20 Fig. 10e: all regions 'off'.

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination
25 in a single embodiment. Conversely, various features of the invention which are, for brevity, described in the context of a single embodiment, may also be provided separately, or in any suitable combination.

30 It is to be recognized that various alterations, modifications, and/or additions may be introduced into the constructions and arrangements of parts described above

without departing from the scope of the present invention
as specified in the claims.

CLAIMS

1. A display device with greyscale capability,
comprising:

5 a first cell wall of a glass or plastics material
having a substantially planar inner surface spaced apart
from and opposed to a second cell wall having a
substantially planar inner surface,
said substantially planar inner surfaces being
10 substantially parallel to each other;
a layer of an electro-optic material between the cell
walls;
a plurality of first electrode structures provided on
the first cell wall and at least one second electrode
15 structure provided on the second cell wall, overlapping
regions of first and second electrode structures defining
pixels;
the electro-optic material being switchable from a
first optical state to a second optical state when
20 subjected to a suitable electric field;
wherein the shortest distance between the electro-
optic material and at least one of the electrode
structures varies substantially within the area of a pixel
whereby electro-optic material in a first region of a
25 pixel will be subjected to a greater electric field
strength than electro-optic material in a second region of
that pixel when a voltage is applied via a first and
second electrode across the pixel so that electro-optic
material in said first part of said pixel will switch at a
30 lower applied voltage than electro-optic material in said
second part, thereby providing greyscale capability.

2. A device according to claim 1, wherein said electro-

optic material is selected from the group comprising:
nematic liquid crystal material, smectic liquid crystal
material, electrophoretic material.

5 3. A liquid crystal display device with greyscale
capability, comprising:

a first cell wall of a glass or plastics material
having a substantially planar inner surface spaced apart
from and opposed to a second cell wall having a

10 substantially planar inner surface,

said substantially planar inner surfaces being
substantially parallel to each other;

a layer of a nematic liquid crystal material between
the cell walls;

15 a plurality of first electrode structures provided on
the first cell wall and at least one second electrode
structure provided on the second cell wall, overlapping
regions of first and second electrode structures defining
pixels;

20 molecules of the liquid crystal material being
switchable from a first alignment state to a second
alignment state when subjected to a suitable electric
field; and

means for distinguishing between the first and second
25 alignment states;

wherein the shortest distance between the liquid
crystal material and at least one of the electrode
structures varies substantially within the area of a pixel
whereby liquid crystal material in a first region of a
30 pixel will be subjected to a greater electric field
strength than liquid crystal material in a second region
of that pixel when a voltage is applied via a first and
second electrode across the pixel so that liquid crystal

material in said first part of said pixel will switch at a lower applied voltage than liquid crystal material in said second part, thereby providing greyscale capability.

- 5 4. A liquid crystal display device with greyscale capability, comprising:

 a first cell wall of a glass or plastics material having a substantially planar inner surface spaced apart from and opposed to a second cell wall having a

10 substantially planar inner surface,

 said substantially planar inner surfaces being substantially parallel to each other;

 a layer of a nematic liquid crystal material between the cell walls;

15 a plurality of first electrode structures provided on the first cell wall and a plurality of second electrode structures provided on the second cell wall, overlapping regions of first and second electrode structures defining pixels;

20 molecules of the liquid crystal material being switchable by an electric field from a first alignment state to a second alignment state;

 means for distinguishing between the first and second alignment states; and

25 a plurality of dielectric steps between the first electrode structures and the liquid crystal material, each step having a length or breadth of at least 10 μm in plan view through the cell walls;

 the dielectric steps causing the shortest distance
30 between the liquid crystal material and one of said first electrode structures to vary substantially within the area of a pixel whereby liquid crystal material in a first region of a pixel will be subjected to a greater electric

field strength than liquid crystal material in a second region of that pixel when a voltage is applied via a first and second electrode across the pixel so that liquid crystal material in said first part of said pixel will
5 switch at a lower applied voltage than liquid crystal material in said second part, thereby providing greyscale capability.

5. A liquid crystal display device with greyscale
10 capability, comprising:

a first cell wall of a glass or plastics material having a substantially planar inner surface spaced apart from and opposed to a second cell wall having a substantially planar inner surface,

15 said substantially planar inner surfaces being substantially parallel to each other;

a layer of a nematic liquid crystal material between the cell walls;

a plurality of first electrode structures provided on
20 the first cell wall and a plurality of second electrode structures provided on the second cell wall, overlapping regions of first and second electrode structures defining pixels;

molecules of the liquid crystal material being
25 bistably switchable between a first alignment state and a second alignment state when subjected to an electric field of appropriate magnitude, sign and duration; and

means for distinguishing between the first and second alignment states;

30 wherein the shortest distance between the liquid crystal material and one of said first electrode structures varies substantially within the area of a pixel whereby liquid crystal material in different regions of a

pixel will be subjected to different electric field strengths when a potential difference is applied via a first and second electrode across the pixel so that liquid crystal material in at least one of said regions will
5 switch at a lower applied potential difference than at least one other of said regions, thereby providing greyscale capability.

6. A device according to any preceding claim, wherein
10 the first electrode structures are secured to an inner surface of the first cell wall by a dielectric adhesive material.

7. A device according to 3-5, wherein the first
15 electrode structures are secured to an inner surface of the first cell wall by a dielectric adhesive material and the means for distinguishing between the first and second alignment states comprises a polariser affixed to an inner surface of the first cell wall, said adhesive material
20 adhering to the polariser.

8. A device according to any preceding claim, wherein the or each second electrode structure is secured to an inner surface of the second cell wall by a dielectric
25 adhesive material.

9. A device according to any of claims 3-5, wherein the or each second electrode structure is secured to an inner surface of the second cell wall by a dielectric adhesive
30 material and the means for distinguishing between the first and second alignment states comprises a polariser affixed to an inner surface of the second cell wall, said adhesive material adhering to the polariser.

10. A device according to any of claims 3-5, wherein a dielectric covering material is provided between the first electrode structures and the layer of liquid crystal material or between the or each second electrode structure and the layer of liquid crystal material, the covering material presenting a substantially planar surface to the layer of liquid crystal material, substantially parallel to an inner surface of the cell walls; whereby the layer of liquid crystal material has substantially constant thickness.

11. A device according to any preceding claim, wherein the first electrode structures are substantially planar and are at least partly covered by at least one dielectric structure the thickness of which varies within the area of a pixel.

12. A device according to any preceding claim, wherein the first electrode structures are separated from said layer by a series of dielectric steps, with the minimum distance between a first electrode structure and said layer either increasing or decreasing between an edge of a pixel and a central region of the pixel.

13. A device according to any of claims 1-5, wherein each of said first electrode structures is connected to a thin film transistor (TFT) of a TFT array.

14. A device according to any of claims 1-5, wherein said first electrode structures comprise a plurality of parallel electrode stripes and wherein said at least one second electrode structure comprises a plurality of

parallel electrode stripes arranged substantially
orthogonally to said first electrode structures.

15. A device according to any preceding claim, wherein
5 said layer has substantially constant thickness.

16. A device according to any preceding claim, wherein
the shortest distance between said layer and the or each
second electrode structure varies substantially within the
10 area of a pixel.

17. A cell wall assembly comprising:
a cell wall of a glass or plastics material having a
substantially planar surface;
15 at least one electrode structure provided on a
substantially planar surface of said first cell wall, the
or each electrode structure being spaced from the surface
of the cell wall by a spacing material; and
a dielectric covering material which overlies at
20 least a part of the or each electrode structure so as to
provide a substantially planar surface;
wherein the shortest distance of a surface of the or
each electrode structure from the planar surface of the
dielectric covering material varies substantially within a
25 specified area.

18. A cell wall assembly according to claim 17, wherein
the or each electrode structure is secured to an inner
surface of the cell wall by a dielectric adhesive
30 material.

19. A cell wall assembly according to claim 18, further
comprising a polariser affixed to an inner surface of the

first cell wall, said adhesive material adhering to the polariser.

20. A cell wall assembly according to any of claims 17-
5 19, wherein said at least one electrode structure comprises a plurality of parallel striped electrode structures.

21. A cell wall assembly according to any of claims 17-
10 19, wherein said at least one electrode structure comprises a plurality of electrode structures each of which is electrically connected to a thin film transistor.

22. A cell wall assembly comprising:
15 a cell wall of a glass or plastics material having a substantially planar surface;
at least one electrode structure provided on a substantially planar surface of said cell wall; and
a dielectric covering material which overlies at
20 least a part of the electrode structure so as to provide a non-planar surface;
wherein the shortest distance of a surface of said at least one electrode structure from said non-planar surface of the dielectric covering material varies substantially
25 within a specified area.

23. A cell wall assembly according to claim 22, wherein the at least one electrode structure comprises a plurality of electrode structures.

30

24. A cell wall assembly according to claim 23, wherein each electrode structure has a length and a width and wherein the shortest distance of a surface of each

electrode structure from said non-planar surface of the dielectric covering material varies substantially within said width.

5 25. A transfer carrier comprising a transfer surface on which is releasably mounted at least one dielectric structure which carries an electrode structure, the shortest distance between a surface of the electrode structure and said transfer surface substantially varying
10 within a specified area.

26. A transfer carrier comprising a transfer surface on which is releasably mounted a plurality of dielectric structures at least some of which carry a plurality of
15 first electrode structures, the shortest distance between a surface of one of the electrode structures and said transfer surface substantially varying within a specified area.

20 27. A transfer carrier according to claim 25 or claim 26, wherein said transfer surface is substantially planar.

28. A method of manufacturing a cell wall assembly for a liquid crystal display device, the method comprising:

25 forming on a substantially planar surface of a transfer carrier, a dielectric structure which extends in a direction perpendicular to said surface by a distance which varies substantially within a specified area;

forming on said dielectric structure at least one
30 electrode structure;

adhering said at least one electrode structure to a major surface of a cell wall of glass or a plastics material; and

removing the transfer carrier.

29. A method according to claim 28, wherein the step of adhering said at least one electrode structure to a major
5 surface of a cell wall comprises adhering said at least one electrode structure to a polariser affixed to said cell wall.

30. A method according to claim 28 or claim 29, wherein
10 said at least one electrode structure comprises a plurality of electrode structures, the method further including forming on said dielectric structure a plurality of busbars, wherein each electrode structure is in electrical contact with a corresponding busbar.

15

31. A method according to claim 30, wherein the step of forming a plurality of electrode structures comprises:

forming a transparent conductor layer on said dielectric structure;

20 applying a layer of photoresist material to said conductor layer;

illuminating said photoresist material through a suitable mask with UV light of sufficient intensity and duration to effect a chemical change in exposed regions of
25 said photoresist;

removing either photoresist which has been exposed or photoresist which has not been exposed; and

etching said conductor layer in regions where said photoresist has been removed, thereby forming a plurality
30 of transparent electrode structures.

32. A method of applying to a display substrate transparent electrode structures and addressing busbars in

a defined alignment relative to each other, the method comprising the steps of:

- 5 (a) forming on a substantially planar surface of a transfer carrier, a series of dielectric structures each of which has a length and a width and which extends in a direction perpendicular to said surface by a distance which varies substantially within said width, each dielectric structure comprising electrode-receiving surface regions separated by a levee, adjacent dielectric
10 structures being spaced apart to define a trench therebetween;
- (b) forming said busbars by at least partially filling each of said trenches with an electrically-conductive material;
- 15 (c) depositing a layer of a translucent conductor material on said electrode-receiving surface regions and in contact with said busbars to form a series of electrode structures defined by said levees;
- (d) affixing said electrode structures and levees to
20 a display substrate by means of a dielectric adhesive material; and
- (e) removing said transfer carrier.

33. A method according to claim 32, wherein said
25 translucent conductor is deposited via an inkjet print head.

34. A method according to claim 32 or claim 33, wherein each levee is joined to an adjacent surface region by a
30 radiused portion.

35. A method of manufacturing a cell wall assembly, the method comprising:

taking a first cell wall of a glass or plastics material having a plurality of first electrode structures provided on a substantially planar surface thereof; and

5 applying a dielectric covering material which overlies at least a part of the first electrode structures so as to provide a non-planar surface;

 wherein the shortest distance of a surface of each first electrode structure from said non-planar surface of the dielectric covering material varies substantially
10 within a specified area.

36. A method of manufacturing a display device with greyscale capability, comprising:

 taking a first cell wall assembly according to any of
15 claims 17-24 and a second cell wall assembly comprising a second cell wall having a substantially planar inner surface and a plurality of second electrode structures provided on the second cell wall;

 arranging said first and second cell wall assemblies
20 so that they are spaced apart with the substantially planar surfaces substantially parallel to each other and with the first and second electrode structures overlapping to define pixels; and

 providing a layer of an electro-optic material
25 between the first and second cell wall assemblies;

 wherein the shortest distance between the electro-optic material and one of said first electrode structures varies substantially within the area of a pixel.

30 37. A method according to claim 36, wherein said electro-optic material is a liquid crystal material and further comprising providing a surface alignment on at least one of said first cell wall assembly and said second cell wall

assembly, to provide at least one desired local orientation to adjacent molecules of said liquid crystal material.

5 38. A method according to claim 37, wherein the surface alignment stabilizes adjacent molecules of liquid crystal material in either of two stable alignment states.

10 39. A method according to claim 37, wherein the liquid crystal material can be bistably switched between at least two optically-distinguishable alignment states.

40. A method according to any of claims 37-39, wherein said liquid crystal material is a nematic material.

15 41. A method according to claim 37, wherein said liquid crystal material is a ferroelectric or antiferroelectric smectic material.

20 42. A method according to claim 36, wherein said electro-optic material comprises finely-divided charged particles in a dielectric liquid carrier, said charged particles being capable of migrating to one of said cell walls under the influence of a suitable electric field.

25 43. A method of manufacturing a liquid crystal display device having greyscale substantially as herein described with reference to the drawings.

30 44. A method of manufacturing a cell wall assembly substantially as herein described with reference to the drawings.

45. A liquid crystal device having greyscale substantially as herein described with reference to the drawings.

5 46. A cell wall assembly substantially as herein described with reference to the drawings.

47. A transfer carrier substantially as herein described with reference to the drawings.

ABSTRACT

DISPLAY DEVICE WITH GREYSCALE CAPABILITY

5 A display device (22) with greyscale capability,
comprises:

a first cell wall (12a) of a glass or plastics
material having a substantially planar inner surface
spaced apart from and opposed to a second cell wall (12b)
10 having a substantially planar inner surface,

said substantially planar inner surfaces being
substantially parallel to each other;

a layer of an electro-optic material (20) between the
cell walls (12);

15 a plurality of first electrode structures (10a)
provided on the first cell wall (12a) and at least one
second electrode structure (10b) provided on the second
cell wall (12b), overlapping regions of first and second
electrode structures (10) defining pixels;

20 wherein the shortest distance between the electro-
optic material (20) and one of the electrode structures
(10a, 10b) varies substantially within the area of a
pixel. Other aspects of the invention provide a cell wall
assembly for manufacturing a display, a transfer carrier
25 for manufacturing a cell wall assembly, and methods of
manufacturing display and cell wall assemblies.

Figure 5

1/11

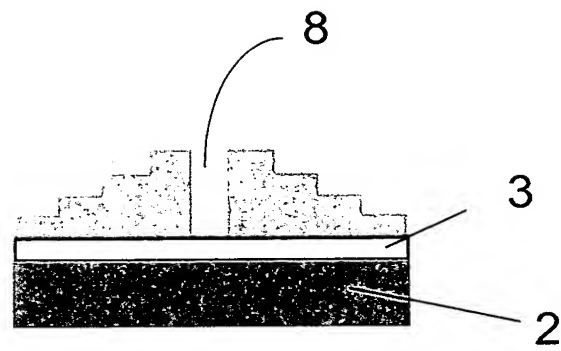
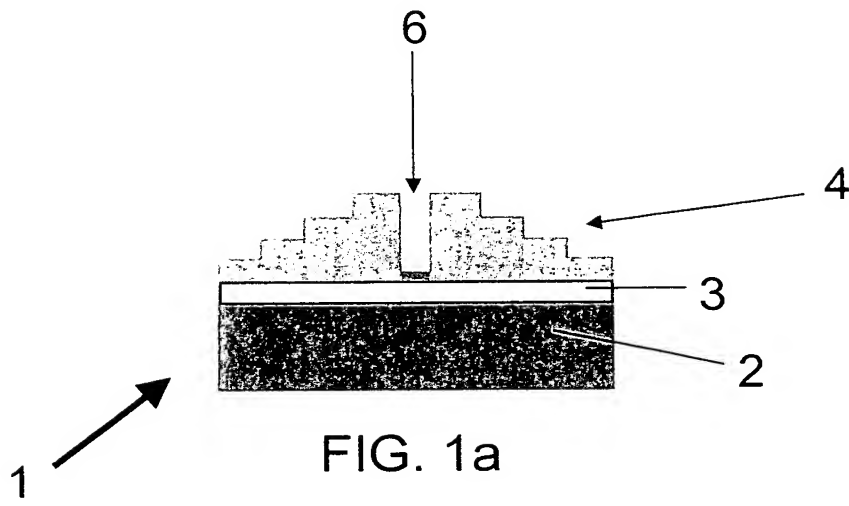


FIG. 1b

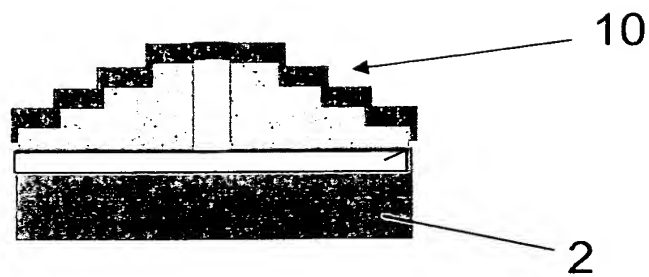


FIG. 1c

2/11

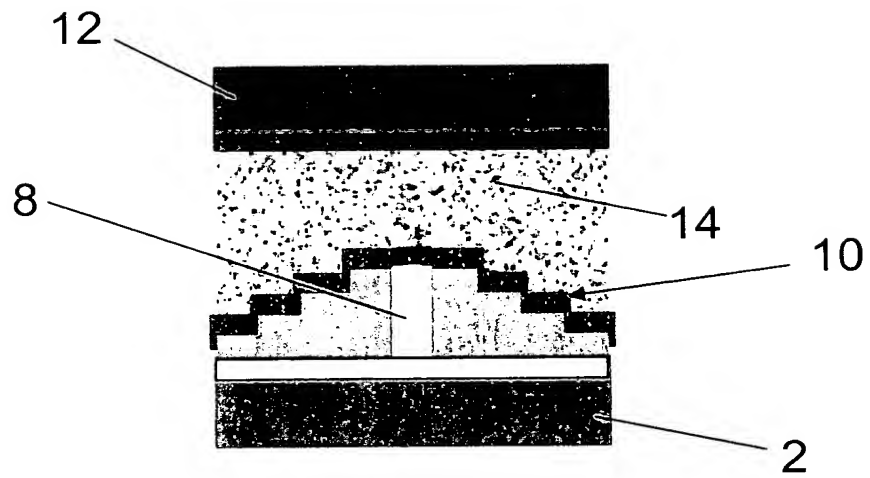


FIG. 2a

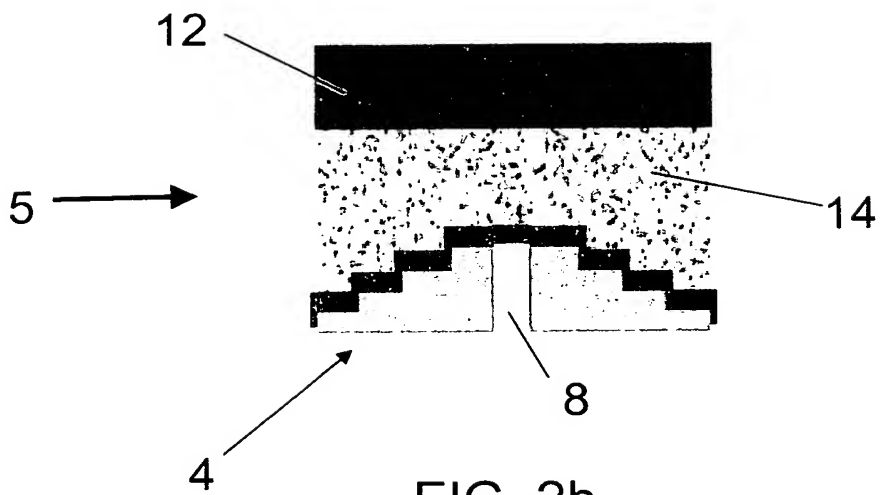
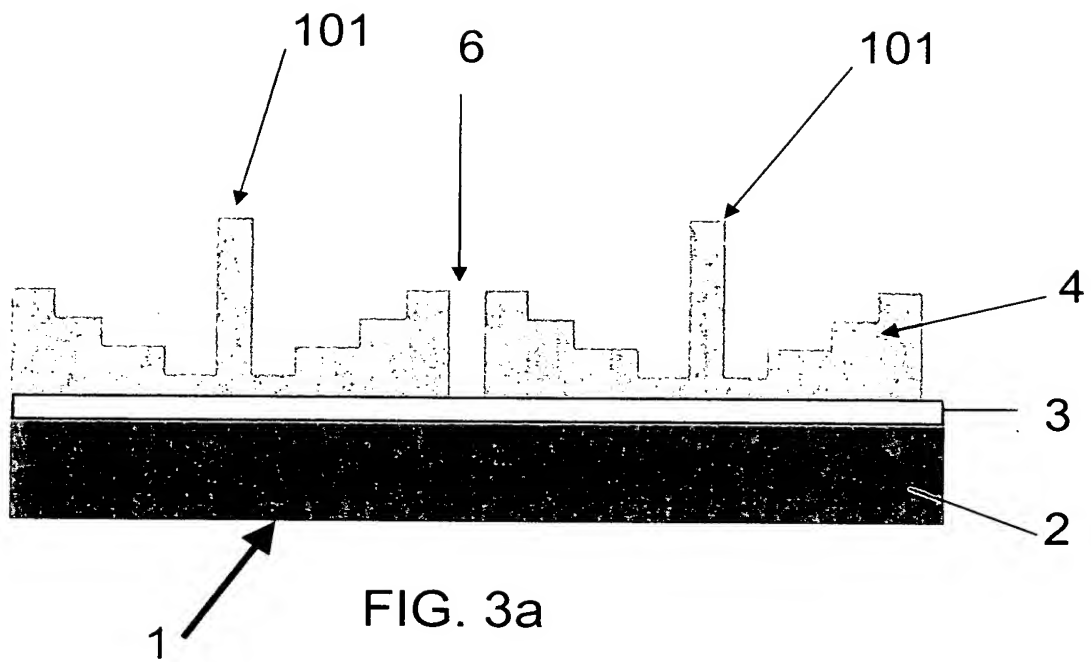


FIG. 2b



4/11

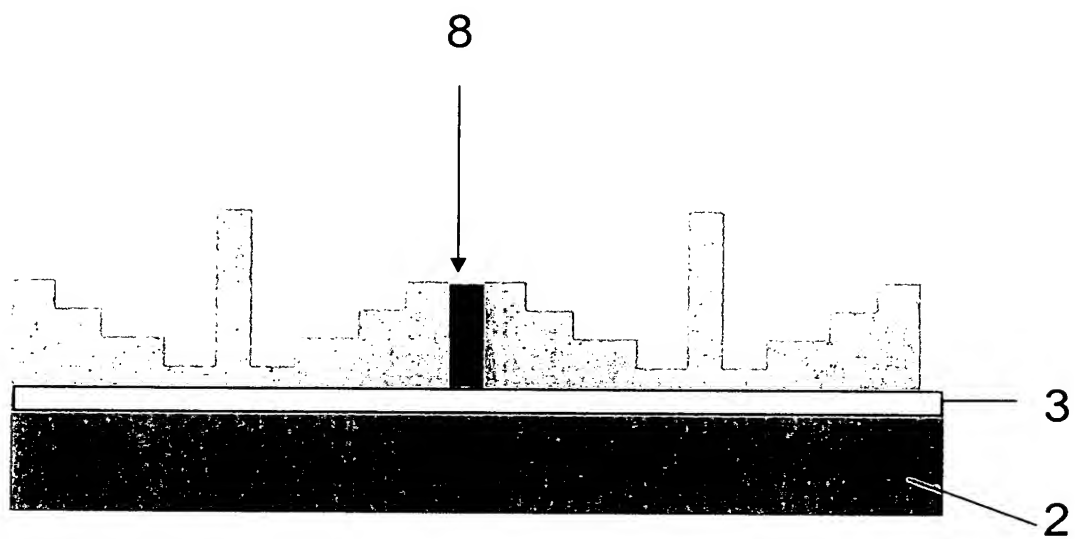


FIG. 3b

5/11

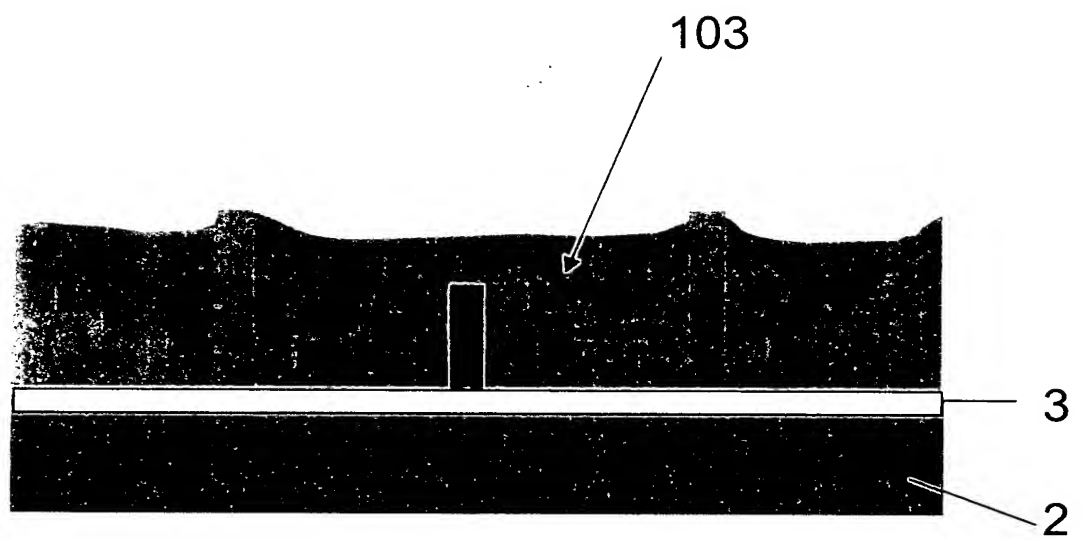


FIG. 3c

6/11

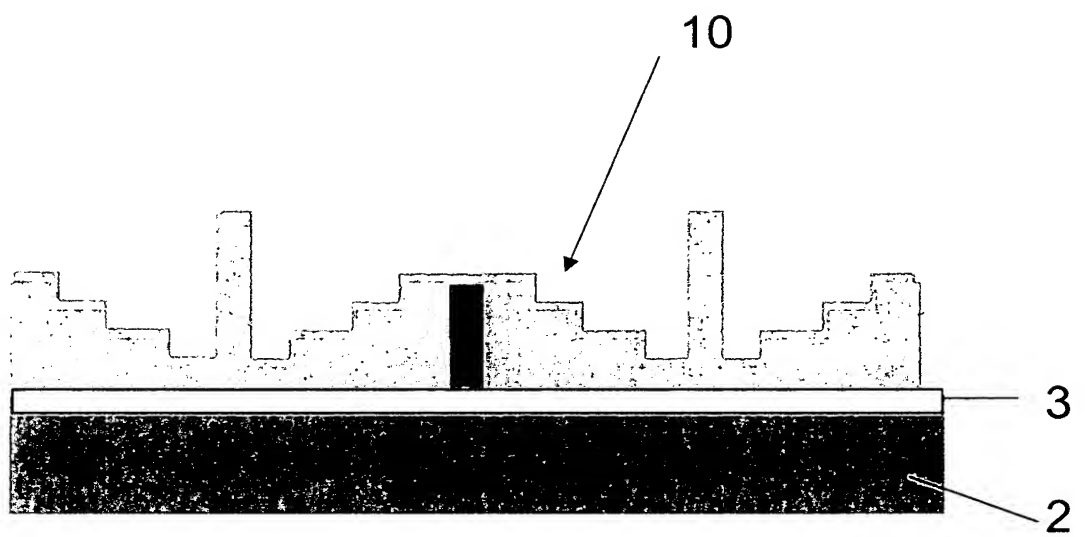


FIG. 3d

7/11

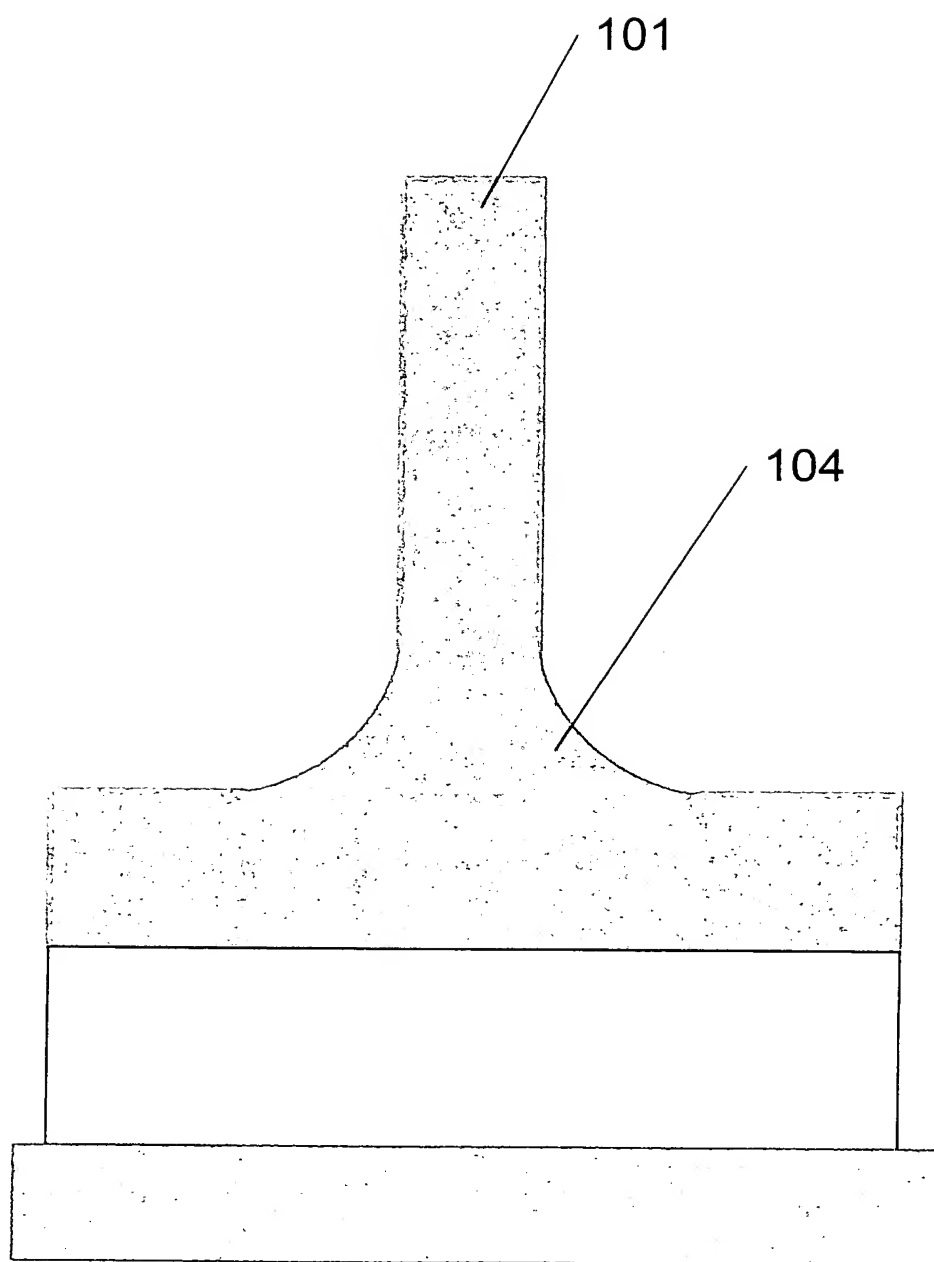


FIG. 3e

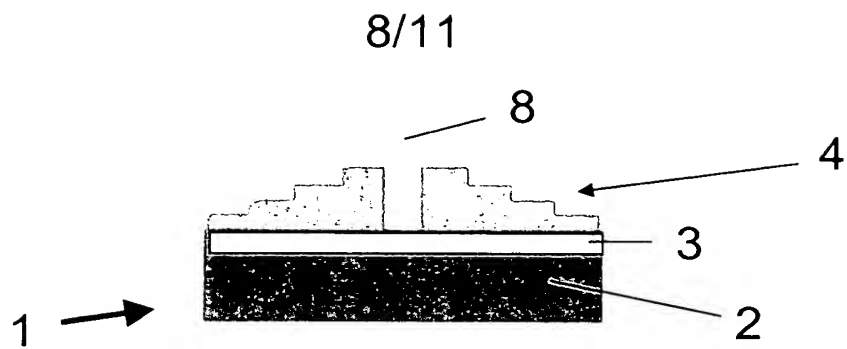


FIG. 4

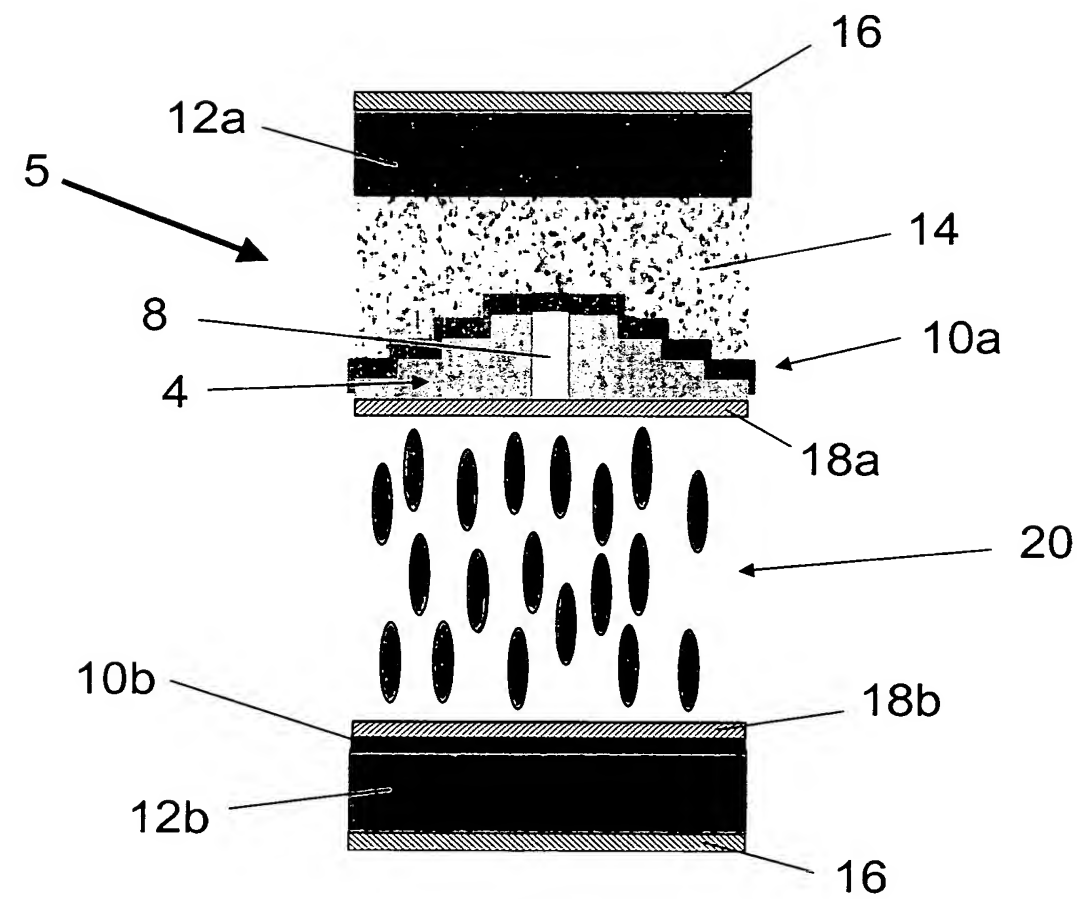


FIG. 5

9/11

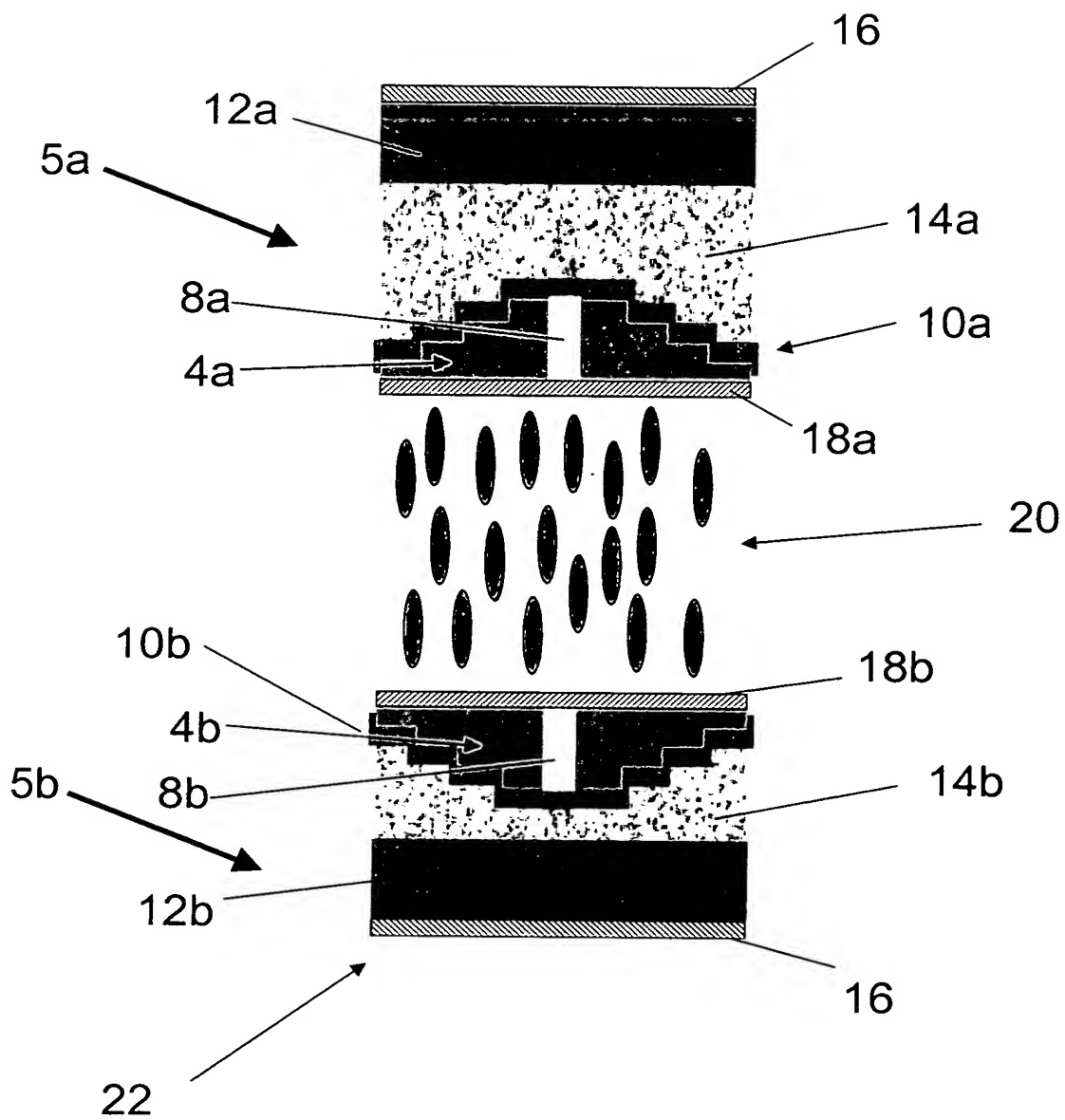


FIG. 6

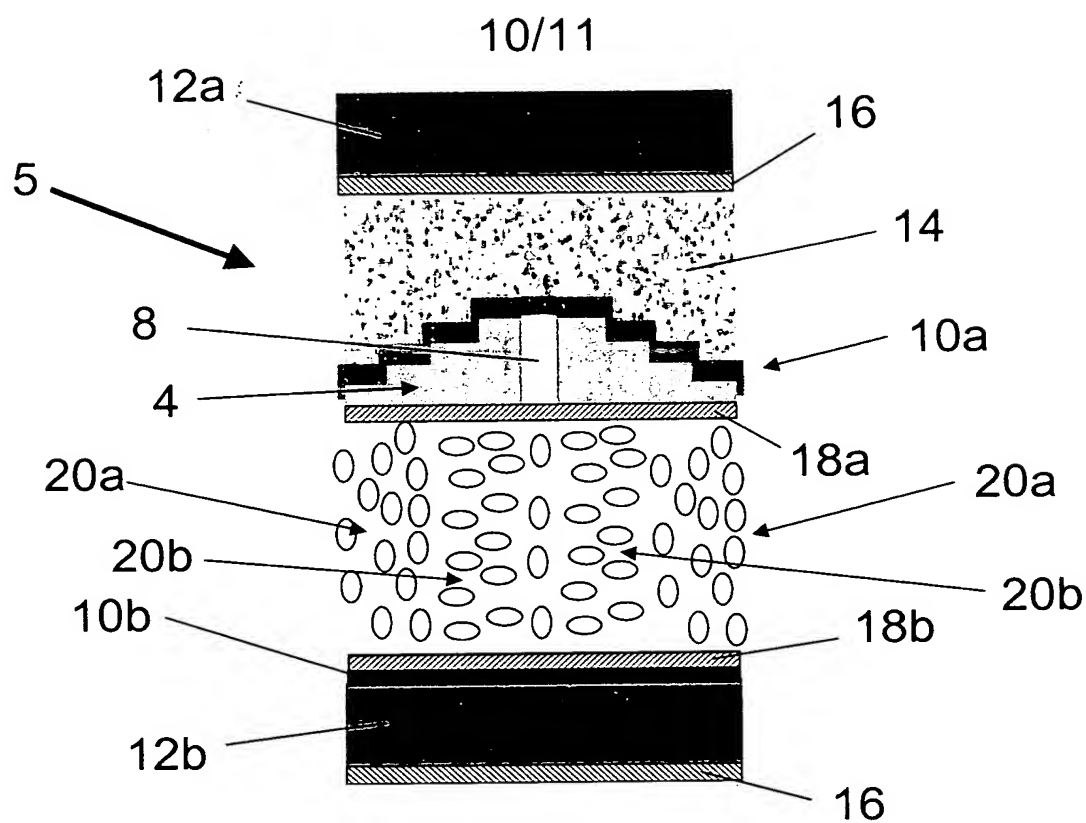


FIG. 7

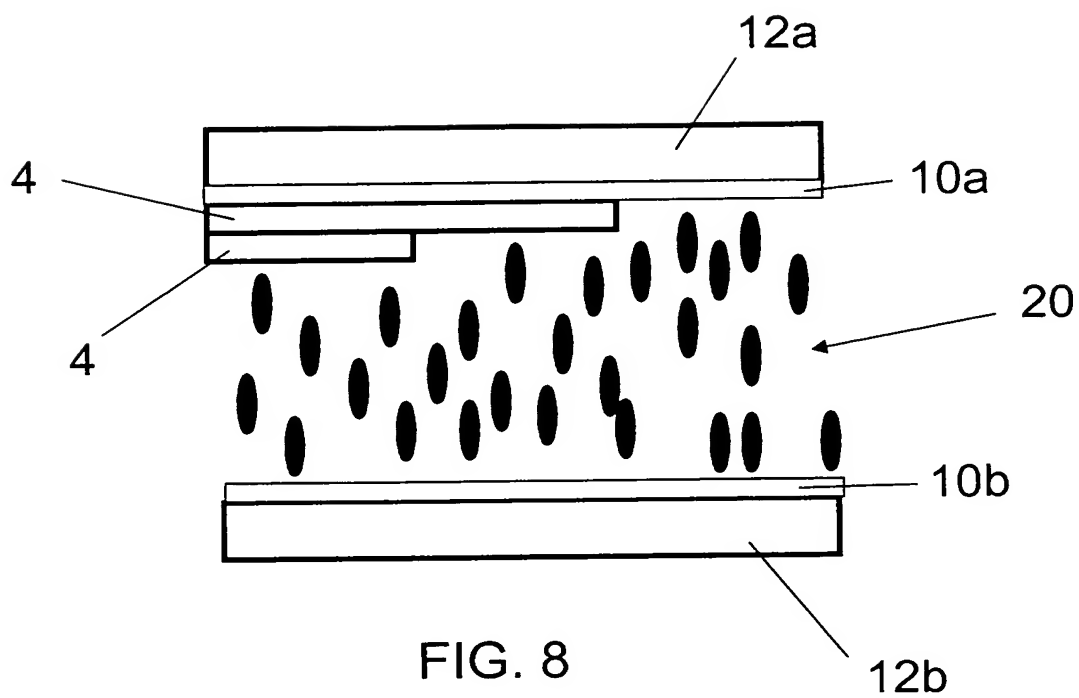


FIG. 8

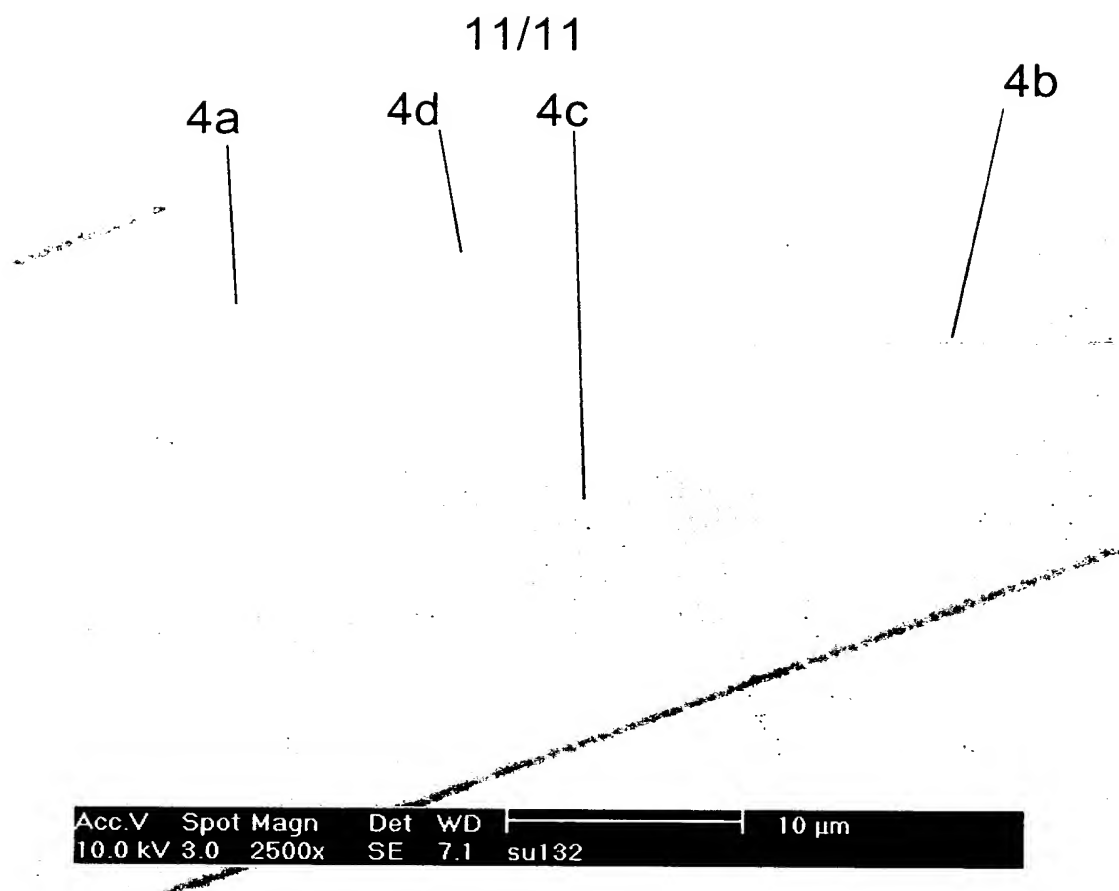


FIG. 9

